



Roving on Ice: Field Testing an Ice Screw End Effector and Sample Collection Tool

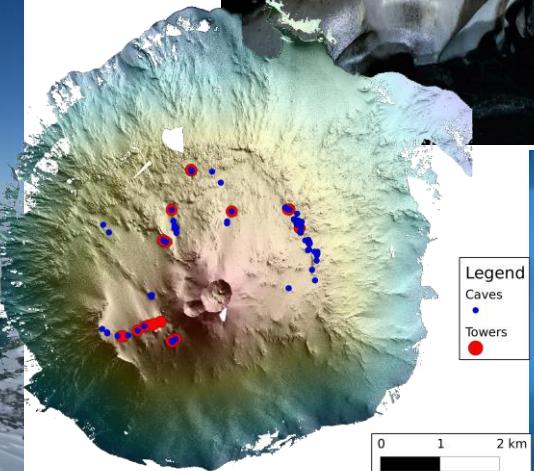
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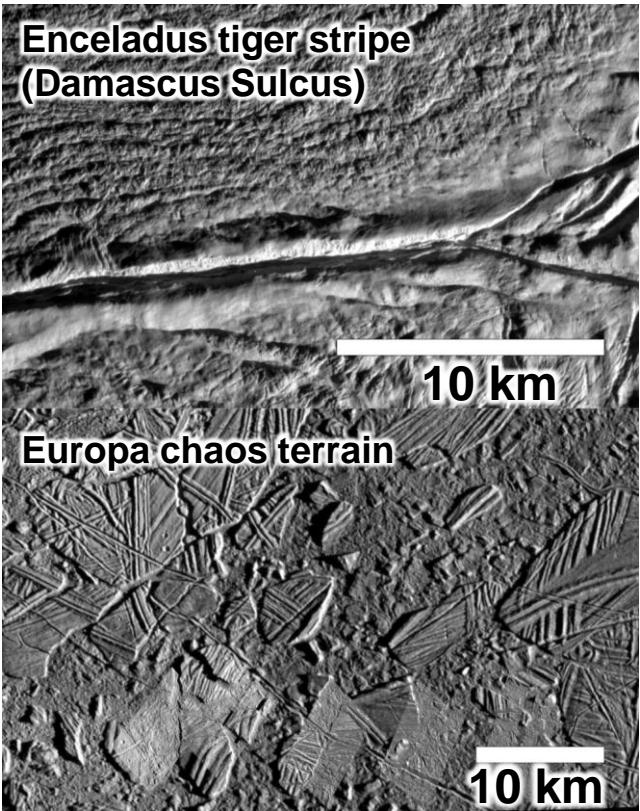


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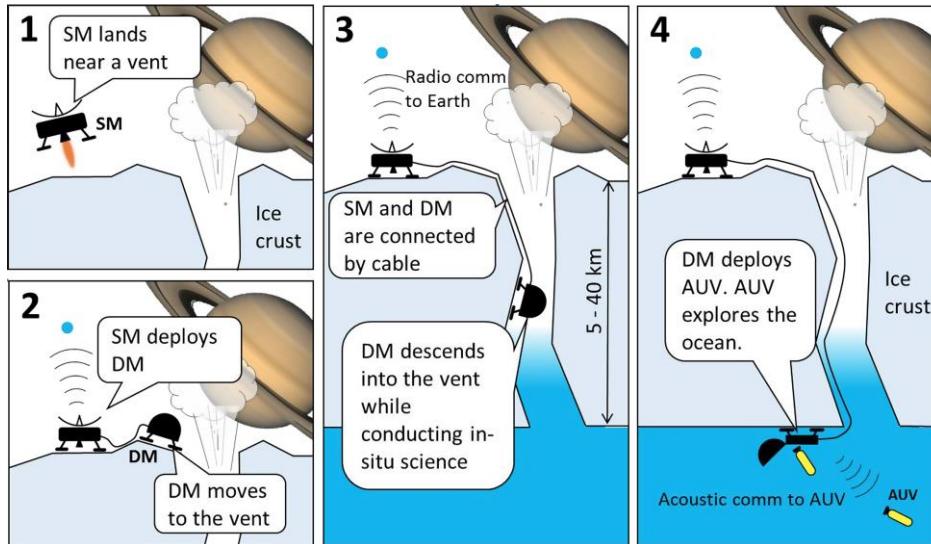
Why climb ice on Earth?



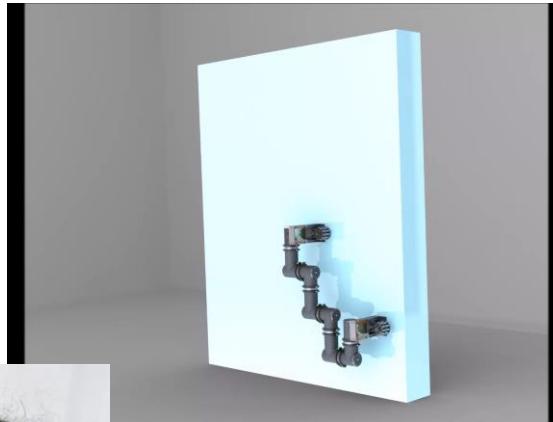
Why climb ice in space?



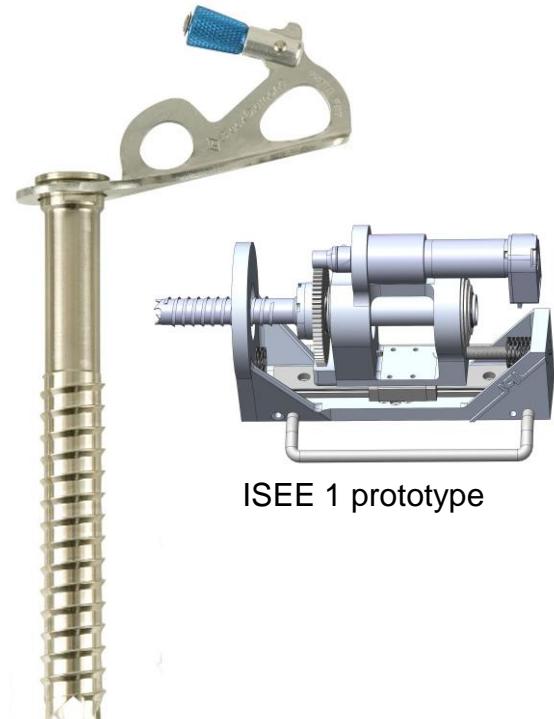
Journey to the Center of Icy Worlds NIAC
Enceladus vent explorer concept (PI: Masahiro Ono)



Gravity-agnostic ice rover concepts



Ice Screw End Effector design iteration



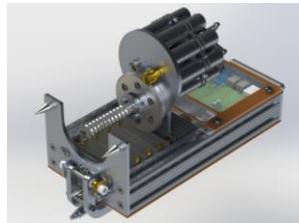
ISEE 1 prototype



Field testing:
Mt Erebus, Antarctica



Lab testing



ISEE 2 prototype



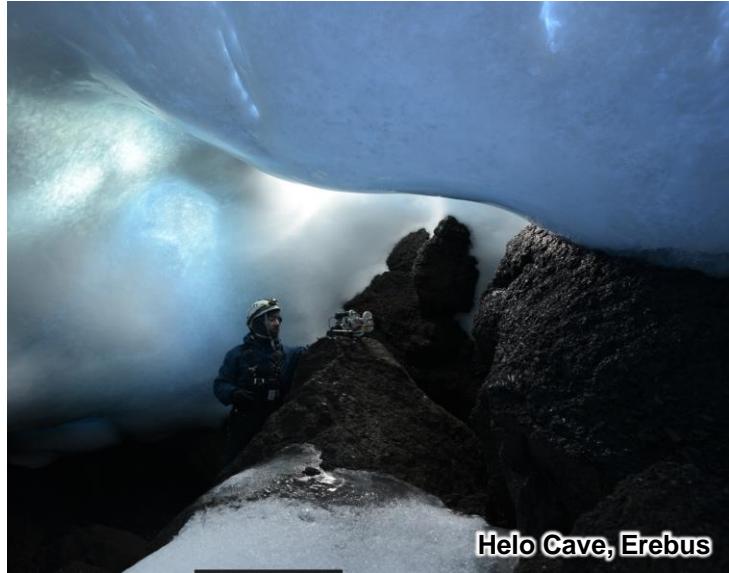
Field testing:
Mt Rainier, Washington



ISEE 3

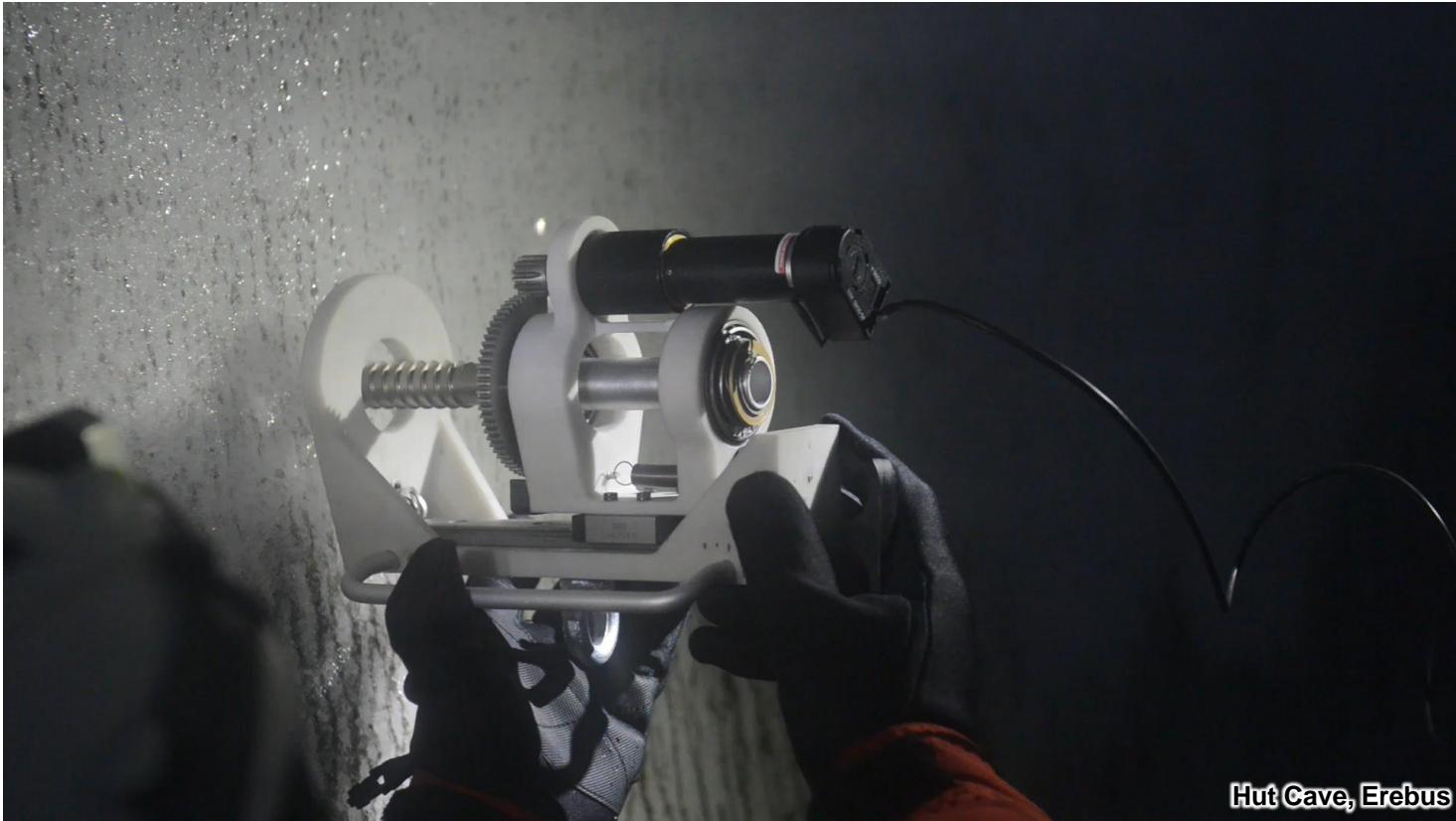
Field Testing ISEE 1 in the Erebus Fumarolic Ice Caves

- Objectives
 - Determine minimum weight on bit required for ice screw insertion
 - Verify ISEE operation in a variety of ice types
 - Verify ISEE operation in a variety of orientations



Helo Cave, Erebus

Field Testing ISEE 1 in the Erebus Fumarolic Ice Caves



Hut Cave, Erebus



Helo Cave, Erebus

Field Testing ISEE 1 in the Erebus Fumarolic Ice Caves



Cathedral Cave, Erebus



Cathedral Cave, Erebus

Field Testing ISEE 1 in the Erebus Fumarolic Ice Caves



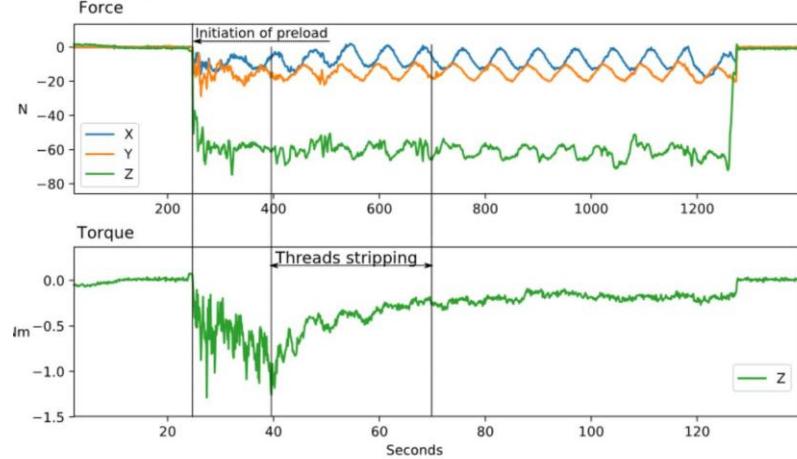
ISEE 1 minimum weight on bit for anchoring

Location	Ice description	Ambient T (C)	Test orientation	Min. WOB	Load
Hut Cave	Granular ice	0	Horizontal	60N	> 350N
Hut Cave	Near pure	0	Horizontal	180N	> 350N
Helo Cave	Near pure	0	Vertical	120N	> 350N
Cathedral Cave	Large hoarfrost	-3	Horizontal	N/A	N/A
Miss Piggy Tower	Near pure	-23	Horizontal	120N	> 350N
Mammoth, CA	Roadside ice	0	Vertical (F/T testbed)	40N	> 350N
JPL	Water ice	0	Vertical (F/T testbed)	40N	> 350N
East Crater Cave, Mt Rainier	Granular ice	~0	Horizontal	40N	> 350N
East Crater, Mt Rainier	Old snow crust	~5	Horizontal	20N	Not tested

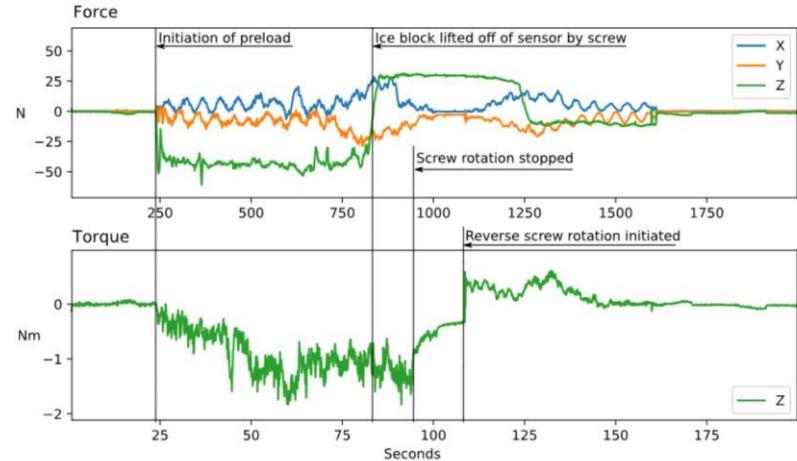
Force / torque measurements



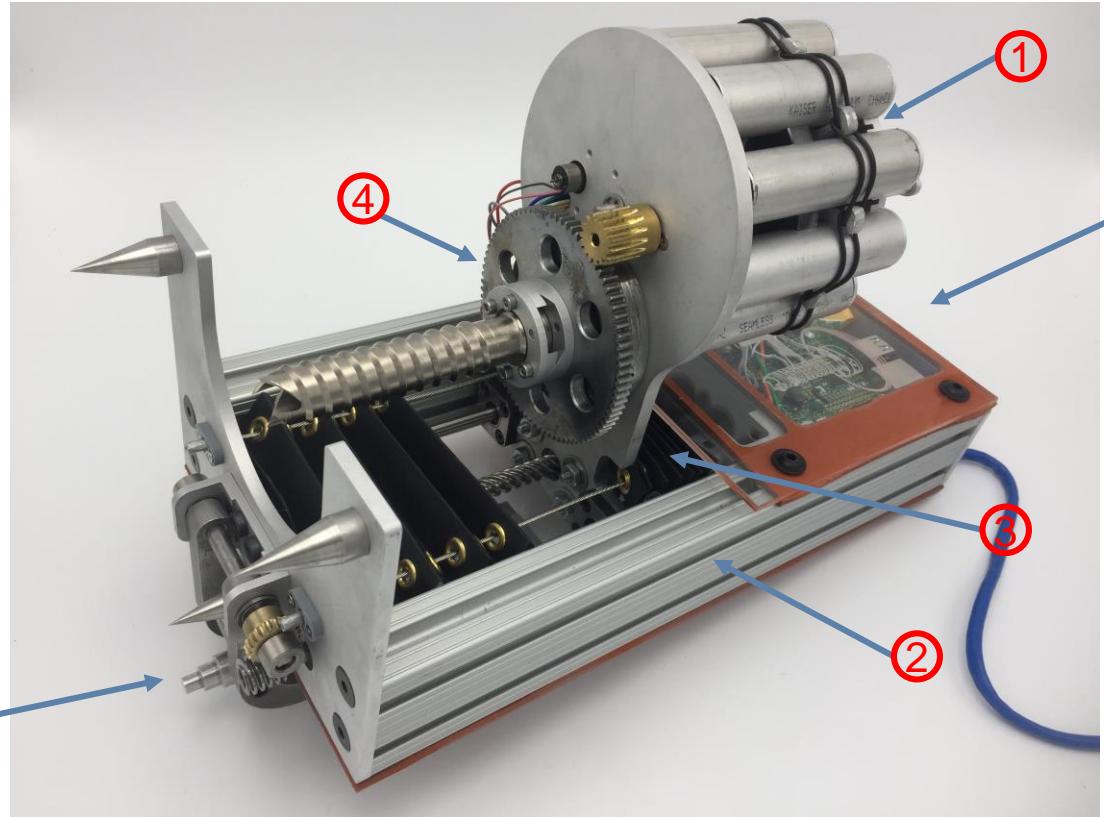
Anchoring success



Anchoring failure

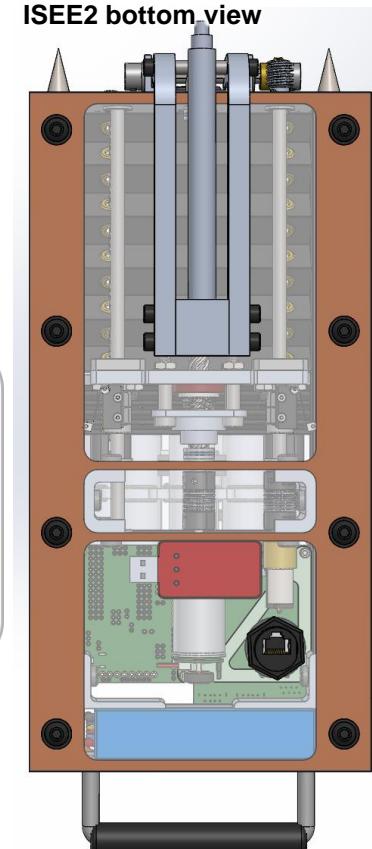
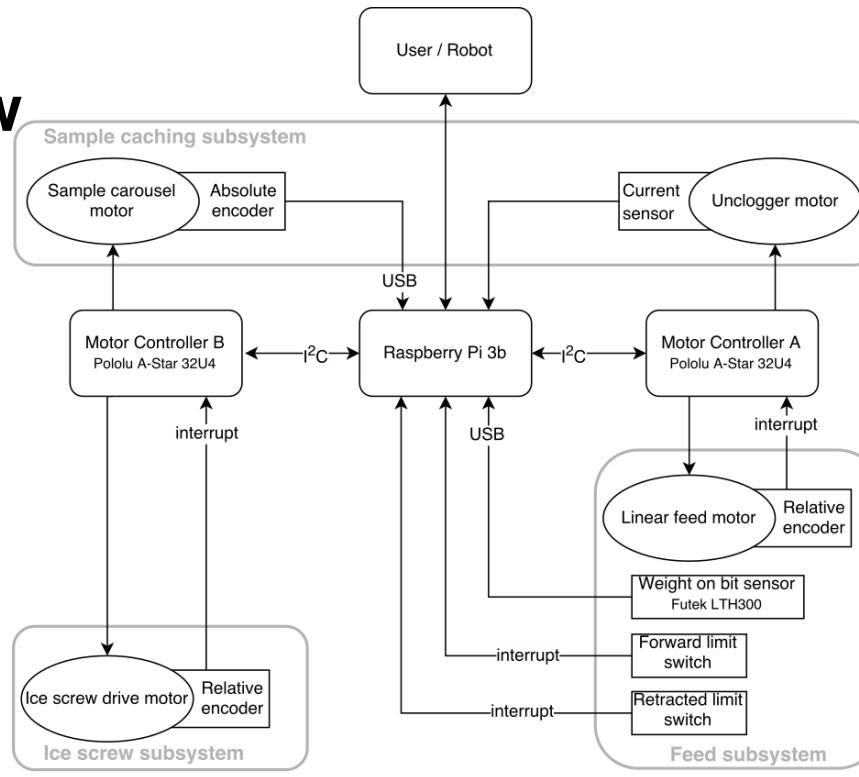
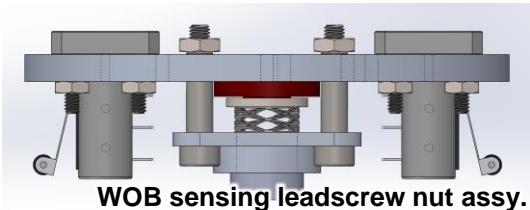
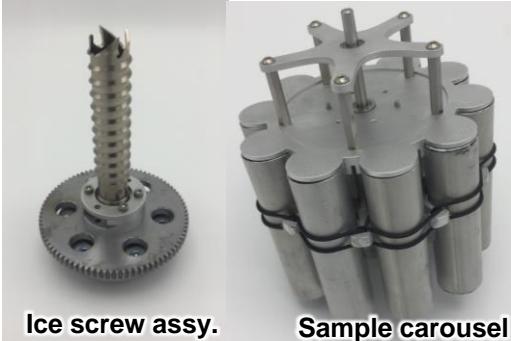


ISEE 2



1. Capsule Carousel
2. Powertrain and Housing
3. Force Sensing Nut
4. Ice Screw Drive System
5. Sample clearing rod
6. Electronics and Battery

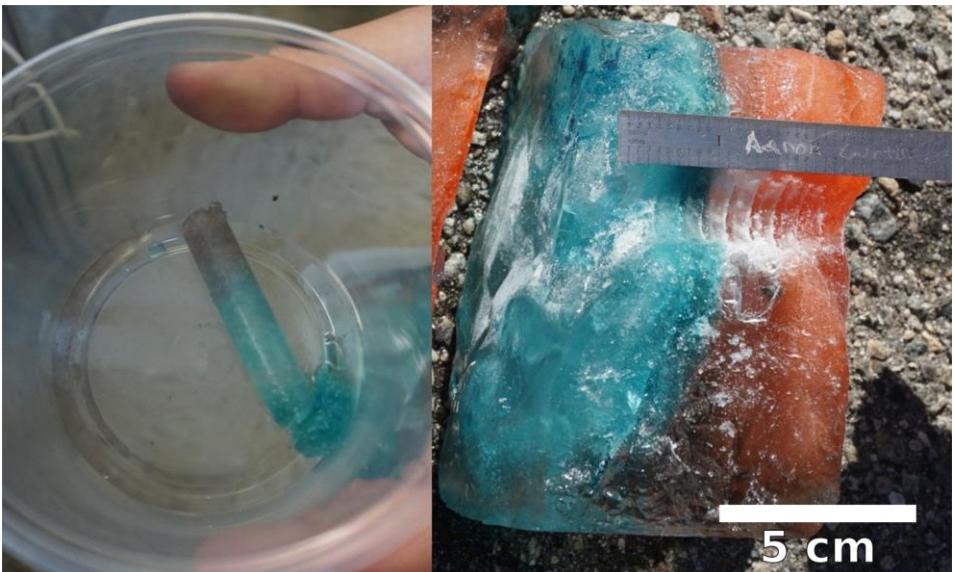
System Overview



Sampling system characterization



Matt Martone with ISEE2 after successful anchoring



Sample depth integrity test

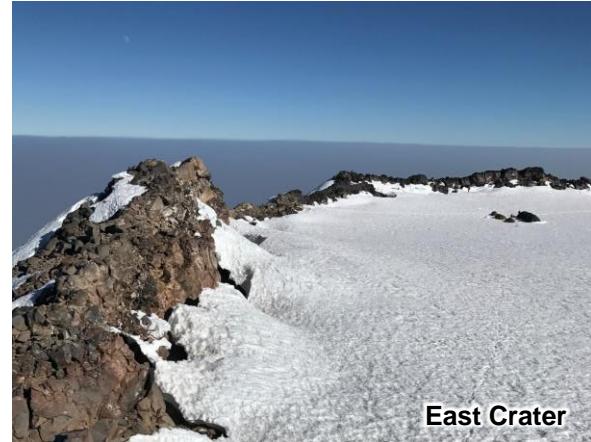
Field Testing ISEE 2 in the Mt Rainier Fumarolic Ice Caves

Objectives:

- Verify operation of new features: linear feed, sample caching, and clearing rod, spikes
- Compare Rainier ice and Erebus ice
- Total organic carbon investigation of Rainier cave ice



Ingraham Flats

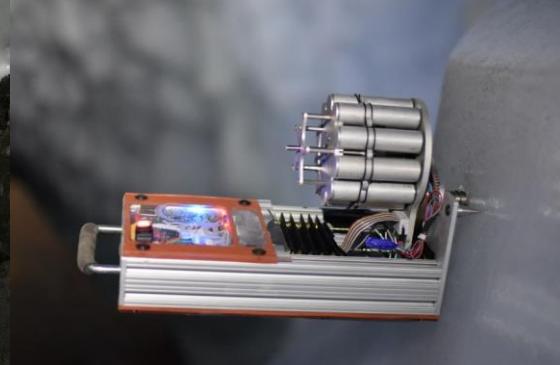


East Crater



East Crater Cave

Field test: Rainier 2017



Field test: Rainier 2017



East Crater, Rainier



East Crater, Rainier

Next steps

- ISEE V3
- Validation in vacuum
- Validation on colder ices
- Comparative studies with other end effectors
- Simple inchworm-style climbing robot “Minimus”



Thanks!





Jet Propulsion Laboratory
California Institute of Technology

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